COMPUTER-BASED DETECTION OF CENTRAL NERVOUS SYSTEM SYNDROMES FOR PUBLIC HEALTH SURVEILLANCE

by

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SUPERVISORY COMMITTEE APPROVAL

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This thesis has been read by each member of the following supervisory committee and by majority vote has been found to be satisfactory.

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FINAL READING APPROVAL

To the Graduate Council of the University of Utah:

I have read the dissertation of Adiseshu Venkata Gundlapalli in its final form and have found that (1) its format, citations, and bibliographic style are consistent and acceptable; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the supervisory committee and is ready for submission to The Graduate School.

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ABSTRACT

The early detection of infectious disease outbreaks is key to their management and initiation of mitigation strategies. This is true whether the disease is naturally occurring or due to intentional release as an act of terrorism. In recent times, this has become evident with the anthrax bioterrorism attacks of October 2001, the occurrence of emerging infections such as West Nile Virus and Severe Acute Respiratory Syndrome and the concern for a new pandemic of influenza based on the spread of H5N1 avian influenza.

Public health surveillance efforts at the University of Utah have been in place for several years and came to the forefront during the 2002 Winter Olympic Games. At that time, an electronic medical record-based system was developed and deployed to perform daily surveillance of patients visiting the clinics and emergency department of the University of Utah Health Care System.

This effort was then followed by a detailed validation of the computer rules used in the surveillance system, with special emphasis on the early detection of central nervous system (CNS) syndromes such as meningitis and encephalitis. These syndromes are of importance to both emerging infections such as West Nile Virus and for NIH/CDC Category B threat agents such as Eastern and Western Equine Encephalitis. True CNS syndromes caused by infectious agents represent a small proportion of patients seen at the emergency department of a large tertiary hospital. "Reason for visit" chief complaint

data were poor predictors for the early detection of CNS syndromes. Orders and early results from the laboratory testing of cerebro-spinal fluid were useful for the early detection of meningitis and encephalitis.

Overall, computer-based surveillance methods have a role to play in the early detection of infectious diseases. In particular, this project has contributed to public health surveillance by moving the field beyond chief complaint data and has shown the validity of using computer-based rules for the detection of meningitis and encephalitis.

This thesis is dedicated to my wife Madhu, son Aditya and daughter Diya who deserve degrees and recognition of their own for their unconditional love, support and patience during my "student" days.

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CHAPTER 1

BACKGROUND

"Eternal vigilance is the price of freedom"
--- Tomb of the Unknown Soldier, USA

Public health surveillance is defined as the systematic on-going collection, analysis and interpretation of health-related data essential to the planning, implementation and evaluation of public health practice, closely integrated with the timely dissemination of these data to those responsible for prevention and control (CDC definition).

In essence, in my opinion, the spirit of public health surveillance can be expressed by morphing the above quote to *"Eternal surveillance is the price of health."* As applied to individuals, it might refer to annual check-ups and screening tests for cholesterol and cancer. As applied to the public's health, it might refer to the monitoring of populations for disease processes, outbreaks, sentinel events or unusual occurrences.

In practice, public health surveillance is performed at various levels. One system that is familiar to most in public health is the "Influenza-Like Illness" or ILI sentinel surveillance system that collects data on health care visits attributable to ILI. Another hallmark of public health is the notifiable disease reporting whereby it is mandatory for medical providers and laboratories to report certain diseases to their local health department. While the list of diseases vary from state to state, many diseases are common to the list. Meningitis and encephalitis are included on most lists, including Utah's, and are important infectious diseases of the central nervous system.

Surveillance can be performed at several locations along the chain of health care, from ambulatory clinics, to emergency departments to acute care hospitals and specialty areas such as long-term care facilities. Data from different locations contribute to different aspects of surveillance and often the composite picture is more informative than individual sites. One important location for surveillance is the emergency department (ED), which has several unique characteristics. During working hours and weekdays, the ED usually serves more ill individuals, while the less sick visit their providers in ambulatory care clinics. During the night and weekends, the ED substitutes for an ambulatory care site. The ED also is frequently where mass casualties are treated as well as the surge from any emergency or illness in the community. Apart from this, the ED often serves as a primary care provider for vulnerable populations such as the uninsured, migrant and homeless populations. For all these reasons, monitoring or performing surveillance in the ED has its advantages.

In this setting, this thesis project addresses two important issues in public health surveillance from a medical and biomedical informatics standpoint. The first paper describes the development and deployment of a surveillance system that was designed during a period of concern in the US. The 2002 Winter Olympics were a high-profile event that were conducted in Salt Lake City, Utah barely 4 months after the anthrax bio-terrorism attacks of October 2001 and 5 months after September 11, 2001. At that time, the University of Utah was the closest hospital to the Olympic

Village and (still is) a major tertiary care center for the community. The paper describes the development of a computer-rule based system that monitored the entire electronic medical record of the patient, starting with the visit to the ED. The system provided access to a rich clinical database that could be accessed to confirm or deny events that were flagged as being unusual. In retrospect, there were no events of public health interest during that time. A seasonal increase in influenza was noted as the Olympics were conducted in February and March 2002.

The second paper describes an important next step in the development of a surveillance system, namely validation. While most surveillance systems have focused on ILI, very few have addressed the surveillance of low-prevalence central nervous system (CNS) diseases such as meningitis and encephalitis. In the second paper, a surveillance system designed to detect CNS syndromes has been validated using a clinical standard of cases. This project also addresses a commonly encountered problem in notifiable disease reporting circles: the completeness and timeliness of reporting of CNS syndromes from an acute care hospital to the local health department.

In summary, this master's thesis in biomedical informatics addresses important problems in the area of public health informatics and contributes to the advancement of the field.

CHAPTER 2

HOSPITAL ELECTRONIC MEDICAL RECORD-BASED PUBLIC HEALTH SURVEILLANCE SYSTEM DEPLOYED DURING THE 2002 WINTER OLYMPIC GAMES

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Abstract

Background. Several computer bio-surveillance systems are in place to detect events of public health (PH) significance. However, most lack access to timely and detailed patient-level data and investigation of alerts places a strain on PH resources.

Methods. Hospital-based infection control professionals led a multidisciplinary team to develop a computer rule-based system that relies on the patient electronic medical record. The rules operated on HL7 messages transmitted by clinical computing systems and encompassed a variety of types of patient-level data, including laboratory test ordering and results, radiology ordering and reports, emergency room and outpatient clinic visits and hospital admissions. Laboratory data were mapped to standard vocabularies and radiology data were processing using natural language processing algorithms before the rules were applied to filter for events of PH interest. For each rule, statistical process controls were applied to generate alerts when levels exceeded two standard deviations above the mean. The system was deployed at a large hospital in Salt Lake City during the 2002 Winter Olympic Games and was accessed three times a day to perform surveillance. Daily reports were provided to local public health agencies after preliminary investigation of the alerts.

Results. Of the 24 rules monitored, 9 generated alerts on 11 different occasions. The only significant event of public health interest noted during the surveillance period was an increase in influenza during the Games. The positive predictive value of the rules varied with a high value (89%) noted for identification of pneumonia from chest x-ray reports by natural language processing algorithms.

Conclusions. With the assistance of a novel computer-based surveillance system linked to the electronic medical record that uses objective, quantifiable events and access to patient data, infection control practitioners could play a front-line role in bio- surveillance and facilitate bi-directional communication with PH agencies.

Introduction

Public health agencies have historically relied on voluntary and mandatory reporting systems, which are not always timely or effective at detecting unexpected or unusual clustering of symptoms in time and space. An important component of this includes the individual provider or "smart observer" recognizing and reporting directly to public health. More recently, in an attempt to foster rapid detection of disease clusters and agents of bioterrorism particularly in association with large-scale public events, various types of syndromic surveillance systems have been introduced in hospitals and health departments (1, 2). Limitations in access to detailed clinical data and the need for efficient statistical analyses to assist in the separation of noise from events of real significance remain barriers to effective public health surveillance of infectious diseases using traditional syndromic surveillance methods.

Hospital infection control units traditionally focus on surveillance of nosocomial infections and more recently on adverse events (3, 4). Infection control practitioners (ICPs) play a key role in reporting notifiable diseases to local and state health departments; thus a cooperative relationship between infection control units and public health agencies already exists. Generally, ICPs have little or no contact with patients at the initial point of contact with the health care delivery system except in circumstances where special isolation precautions are being considered. We believe that through enhanced *monitoring* of patients at the initial point of contact, infection control units may be able to further help public health agencies overcome barriers to timely recognition of community outbreaks. Based on their access to the detailed electronic medical record, an added advantage would be that the infection control practitioners could review details and make the initial determination if a local hospital-based unusual occurrence is of significance and requires further investigation, thus preserving precious public health resources.

A dilemma currently faced by infection control practitioners is the level of alertness and resources needed to monitor for events of public health significance and how to vary that with the national and local homeland security threat level. Computer rule-based programs operating on clinical data from the electronic medical record may play a particularly useful role in this regard. We describe the deployment of a rule-based computer system to assist hospitals in performing real-time public health surveillance that can be used in periods of high alert or special events and for routine practice. The system was specifically developed and deployed for use during the 2002 Winter Olympic Games.

Setting

University Health Care is the only academic medical center in Salt Lake City, Utah and a large component of the health care system in the area. With 500,000 emergency room/outpatient visits and 17,000 admissions per year, the 400-bed tertiary care University Hospital is the centerpiece of this system that provides primary and specialty referral care in several locations to residents of a large area that includes the metropolitan Salt Lake County, the entire state of Utah and the neighboring states of Idaho and Wyoming.

The 2002 Winter Olympic Games were conducted in Salt Lake City, Utah from February 8 – 24, 2002. Participants and officials of the Games resided in the Olympic Village, which was adjacent to the University Hospital. The Village had an average daily census of 2500 individuals during the Games. The University Hospital emergency room was the closest to the Olympic Village and the hospital was also responsible for operating the medical clinic in the Village that provided primary and specialty care to athletes, staff and volunteers during the Games.

Technical Methods and Design Features

Data repository and mapping (Figure 1). The technology platform or software framework used for this study was the TheraDoc Antibiotic Assistant™ developed by TheraDoc™, Salt Lake City, UT. The central component of the system was patient-level data in HL7 format representing ADT (admit-discharge-transfer), laboratory and radiology databases at the University of Utah Health Sciences Center. These, along with other elements, are part of the electronic medical record used at the University Hospital. The data were collected in real-time, appearing in the source system and TheraDoc™ at practically the same time. The feeds were first mapped to standard vocabularies for use by the surveillance system. Laboratory tests were mapped to LOINC codes (Logical Observation Identifier Names and Codes), which are universal identifiers for laboratory

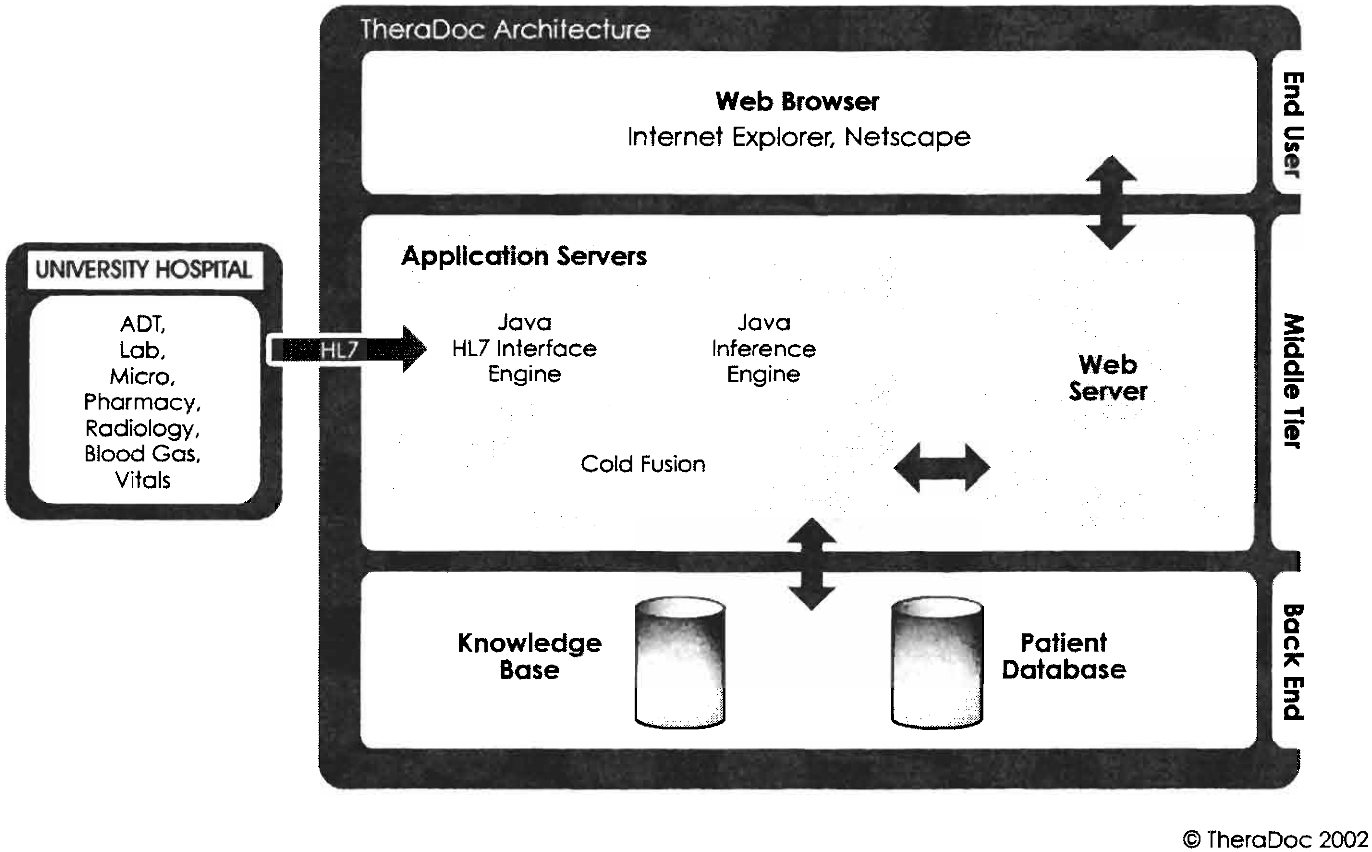

Figure 1. Architecture and flow of information and for public health surveillance at the University of Utah School of Medicine

data that allow health care system computers to fully understand data sent by laboratories (5-7). Results of microbiology tests (negative or positive with name of organism) were mapped to SNOMED-RT (Systemized Nomenclature of Medicine – Reference Terminology) (8), which is a system by which clinical data can be compared and aggregated across different information systems. Radiology tests and reports were delivered in free text and language-processing algorithms were applied to the feeds to retrieve relevant reports using a keyword search in conjunction with a negation template that looks for terms that would negate a positive finding in the free text (e.g., "no" in no pneumonia).

Applying rules to data/inference engines. Specific business rules were developed and applied to processed data to filter for events of interest to public health in the form of "if-then-else" rules. The categories of rules are shown in Table 1.

Patient contact with health care system. Rules pertaining to patient contact with the health care system tracked patient visits to the emergency department and outpatient clinics of the University Hospital and traced the progress of those patients to discharge from these sites, admission to the hospital, or to death within 24 hours of admission, as applicable. This provided numbers of visits to outpatient sites (and specifically the emergency department), numbers of patients admitted to the hospital and a direct measure of acuity of the patient (i.e. whether admitted to the intensive care unit or ward).

Volume and results of tests. These were tracked for orders of influenza tests, blood cultures, cultures of spinal fluid, stool cultures, head imaging studies and chest x-rays. Once results were available, these items were tracked for volume of positive influenza tests and positive microbiology results from sterile body sites. Natural language

Table 1. Categories of items tracked by electronic medical record-based public health surveillance system.

Patient contact with health care system	**Infection Syndromes (with hierarchical rules)**
Visits to the Emergency Department	Influenza
Visits to University Hospital outpatient clinics	Level 1 Influenza test order
Admissions to the ward	Level 2 Pneumonia by x-ray
Admissions to the intensive care units	Level 3 ↑/↓ WBC or bandemia
Death within 24 hours of admission	Level 4 Blood culture ordered
	Level 5 Hospital admission
Volume of test ordering	
	Pneumonia
Anthrax test	Level 1 Pneumonia by x-ray
Blood cultures	Level 2 ↑/↓ WBC or bandemia
Tests on spinal fluid	Level 3 Blood culture ordered
Lymph node site-specific test	Level 4 Hospital admission
Tests for influenza	Level 5 Critical Care admission
Stool cultures	
Non-respiratory viral tests	Diarrhea
Orders for head imaging	Order for stool culture
Orders for chest x-ray	
	Lymphadenitis
Test Results	Microbiology test order from lymph node source
Positive influenza tests	
Positive microbiology results for sterile body sites	Meningitis
	Level 1 Order for CSF test
Atypical lymphocytosis	Level 2 ↑/↓ WBC or bandemia
Increased white blood cell count /with bandemia	Level 3 Blood culture ordered
	Level 4 Order for head imaging
Increase serum creatinine	
Chest X-ray reports suggestive of pneumonia	Viral Rash
Chest X-ray report for widened mediastinum in non-trauma patients	Viral test from non-respiratory source
Chest X-ray report for hilar adenopathy	
	Sepsis
	Level 1 Critical care admission
	Level 2 Blood culture ordered
	Level 3 ↑/↓ WBC or bandemia

processing algorithms (with negation templates) were applied to radiology reports for chest x-rays to filter for those suggestive of infectious pneumonia without evidence of trauma (evidence of consolidation, opacity or pleural effusion suggestive of infectious process). As laboratory testing is commonly performed on patients with different conditions, these rules were used multiple times in the detection of different infection syndromes.

Groups of rules. There were reviewed together to detect infection syndromes such as pneumonia, hospitalized influenza, diarrhea, meningitis, sepsis and unexplained death within 24 hours of admission. The rules were assembled in a hierarchical manner to reflect increased acuity of -illness. Patients with increasing levels of pneumonia syndrome were those that had a chest x-ray suggestive of an infectious pneumonia combined with abnormal blood counts, ordering of blood cultures and admission to the hospital. The influenza syndrome was designed to track those patients that had a positive test for influenza and were subsequently found to have pneumonia and were hospitalized. For diarrhea, lymphadenitis, sepsis and meningitis syndromes, the higher level rules were designed to track patients that had positive test results that were indicative of an infectious process. Patients that satisfied the criteria for a nonrespiratory viral test were those that had orders for a viral test from a source that was not from the respiratory tract (in other words, designed to identify patients with unusual skin lesions). The unexplained death syndrome patients were those that expired within 24 hours of admission with no immediately discernible explanation for their death.

GIS component. An enhanced feature was the capability to map the patients to their specific zip code (from address provided at time of patient registration) and provide a geographical density map to display local patterns of alerts (e.g., distribution of patient visits to the emergency room based on home zip code or multiple stool cultures ordered from patients with the same zip code, indicating the possibility of an outbreak of infectious diarrhea).

Statistical Process Control (SPC). For each computer-based rule, statistical process control algorithms based on cumulative sums (CUSUM) (9) were applied to provide means and levels that are one- and two- standard deviations above normal. With the aim of detecting unusual occurrences, CUSUM is a quality control method borrowed from manufacturing that cumulates sums of the differences between the frequencies of variables based on observed data and their expected means, thereby detecting small shifts from the mean. SPC graphs were available in different time units of aggregation and were viewed using the prior week, month or year as frame of reference. An upper and lower warning limit was established at one standard deviation from normal and an upper and lower control limit was established at two standard deviations from normal. These were then displayed in a graphical format for assessment. An alert or notification was automatically generated when the upper control limit was exceeded for any rule. The SPC graphs were based on baseline data encompassing the prior 2 years of visits to the University Hospital and thus accounted for day of the week and seasonal variation.

Web interface. The system was available as a web-based application via the hospital intranet thus assuring rapid and round-the-clock accessibility to members of the hospital infection control unit. A graphical user interface with menus was provided for display of data. Frequencies of alerts generated from the rules were displayed individually or in groups, by specific or all hospital locations, by a specified or custom time frame and results collated by day, week or month.

Once an alert was identified, individual patients contributing to that alert were displayed in a pop-up window. At this stage, individual patient data and results were available as a drill-down feature to review the detailed electronic medical record of the patient.

Surveillance methodology

The following protocol was followed for tracking the surveillance system during the period February 1- 28 and March 1-3, 2002 coinciding with the 2002 Winter Olympic Games. The surveillance was started 7 days before the opening of the Games and continued for 7 days after the closing ceremony. A surveillance session consisted of one member of the infection control unit (AVG) accessing the system to perform a detailed review of all results generated by the four categories of rules. Surveillance sessions were conducted three times a day (morning, afternoon and evening) during the Olympics. Data were examined at the aggregate level for alerts generated by the rules with respect to numbers of patient visits, admission, tests ordered and infection syndromes. Individual patient level data were accessed through the drill down feature of the system to review the electronic medical record including results of tests, radiology reports, progress and procedure notes. SPC graphs were reviewed for all rules on a daily basis and all alerts (generated when rules exceeded the upper control limit) were specifically reviewed for events of possible public health significance. For completeness, chart review of patients of interest was performed on subsequent days to determine final diagnoses based on the availability of test results. Aggregate data regarding events of possible public health significance were deidentified and conveyed to the Olympic Medical Commission, Organizing Committee and local public health agencies for review. Due to the high profile nature of the Olympics, it was decided to perform manual review of the alerts generated by the system.

Rules refinement. This was performed by an on-line review of the alerts generated by the system prior to deployment of the system. After the study period, positive predictive values (PPVs) were determined for each rule by a detailed retrospective review of the electronic medical record for all alerts generated by the system. Exact 95% confidence intervals were calculated using STATA 9.0 (StataCorp, College Station, TX). A true sensitivity and specificity could not be calculated in this study as the records of only those patients that generated alerts were reviewed.

Security and privacy issues. The system was accessed through the hospital electronic medical record (intranet environment) and was thus subject to the same patient privacy and security protocols and log-in assurances of the University Hospital. A higher level of security was achieved as the surveillance web pages were made available only to members of the University Hospital infection control unit by specific log-on privileges.

The Institutional Review Board of the University of Utah reviewed the surveillance protocol and deemed it exempt from review.

Results

Real-time surveillance during the Olympics (high-profile event period). A typical surveillance session required an average of 30 minutes to review all alerts.

Access to the system was reliable from on-site and remote locations and there were no technical difficulties observed in using the web interface.

Twenty-four rules were monitored for statistical alerts based on SPC graphs during the Olympics (Table 2). The number of patient visits to the emergency department (screen shot in Figure 2) and hospital admissions exceeded the SPC upper control limit on 2 separate days. A manual review of admitting diagnoses/chief complaints of those patients (by members of the infection control unit in conjunction with the hospital staff) revealed no unusual patterns with respect to clusters of illness. Orders for head CT imaging, cerebro-spinal fluid testing and stool cultures exceeded their SPC upper control limit on one occasion each, with no unusual pattern noted in results. Infection syndromes triggered statistical alerts on 6 separate days. A review of those days and results of those tests revealed no unusual pattern in the distribution of infectious syndromes involving pneumonia, diarrhea or sepsis.

Influenza activity during the Olympics. The surveillance system detected a dramatic increase in the number of influenza cases (total of 41) during February 2002, as compared to the prior month (January 2002, 6 cases) and prior year (February 2001, 4 cases). In reviewing this activity, it was noted that the number of patients diagnosed with influenza during February 2002 at the University Hospital (5 cases) remained constant. However, during the study period, a separate project that involved prospective clinical and laboratory surveillance for influenza was being carried out among athletes and personnel in the Olympic Village (10). These active surveillance data were incorporated into the system and contributed directly to the increase in cases. This increased influenza

Table 2. Incidence measures and statistical alerts generated for selected rules at the University Hospital, February – March 2002

Rule	Lower warning limit	Lower control limit	Upper warning limit	Upper control limit	Mean	# of Alerts	Comments
Contact with health care							
Visits to Emergency	48	56	91	99	74	1	NS
Hospital admissions	3.8	7.7	23.4	27.4	15.6	1	NS
Critical care admissions	0	0	8.4	10.5	4.3	-	-
Volume of test ordering							
Orders for head CT	0	0	7	9	3	1	NS
Orders for blood cultures	0	0	9	11	4	-	-
Orders for spinal fluid	0	0	2	3	<1	1	NS
Orders for influenza tests	0	1	11	14	6	1	Significant*
Orders for tests on nodes	0	0	0	0	0	-	-
Orders for stool cultures	0	0	1	2	<1	1	NS
Test results on chest x-ray							
Pneumonia	0	0	4	5	1	-	-
Consolidation of lung	0	2	12	14	7	-	-
Mediastinal widening	0	0	0	0	0	-	-
Infection syndromes							
Pneumonia	0	3	15	18	9	1	NS
Diarrhea	0	0	1.6	2	<1	1	NS
Influenza	0	2	12	15	7	3	Significant*
Meningitis	0	0	2	3	1	-	-
Sepsis	0	1	10	12	5	1	NS
Unexplained death < 24 hr of admission	0	0	0	0	0	-	-

*Influenza testing and number of positive cases increased due to the active surveillance program that was ongoing in the Olympic Village during the study period (10).
NS = not significant

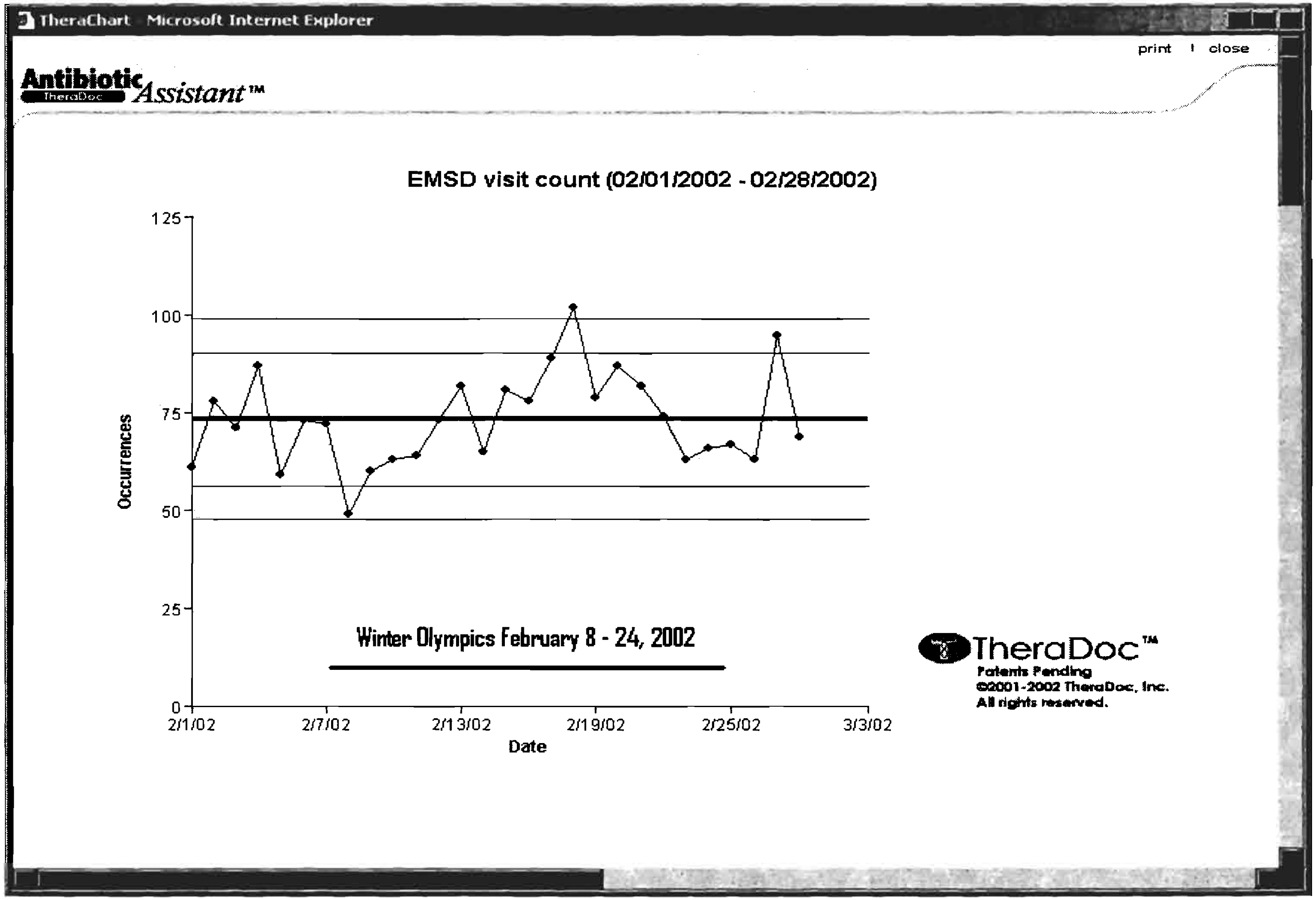

Figure 2. Screen shot of SPC graph for alert generated on numbers of emergency department visits during the study period. The Winter Olympic Games were held from February 8 – 24, 2002.

activity was the only confirmed public health event of significance that was reported to the local public health authorities during the Olympics (11).

Positive predictive values (PPV) for the rules (Table 3). Evaluation of the rules focused on groups of rules for infectious syndromes rather than those rules based on single data sources such as patient contact with health care system, volume and results of single tests ordered. The PPV of computer-based detection of pneumonia from chest x-ray reports ranged from 61 to 89 depending on the rule. In other words, the probability of a person identified by the system as "pneumonia" having clinician-confirmed true pneumonia varied between 61% and 89%. For a radiology report indicative for a case of pneumonia with the use of words specifically mentioning the possibility of "pneumonia," the PPV was 89. Reports indicating either consolidation or pleural effusion as proxies for pneumonia were less useful (PPV 61 and 81 respectively). In reviewing the radiology reports of those patients generating alerts as pneumonia based on the "consolidation" rule, the most common false trigger noted was the misinterpretation of the words "no clear focal consolidation" or "no evidence for consolidation" as pneumonia by natural language processing algorithms (seen in 43% of false positives), followed by the misinterpretation of "basilar linear opacities" of atelectasis as pneumonia (seen in 37% of false positives).

In evaluating the rule intended to identify hospitalized patients with a diagnosis of influenza and pneumonia, it was noted that there were only 4 patients with an alert for pneumonia by chest x-ray in patients who had had an influenza test ordered. Of these, only 1 patient had a true pneumonia as diagnosed by chest x-ray and a positive influenza test (PPV was 25%).

Table 3. Positive predictive values for selected rules evaluated during study period using the public health surveillance system at the University Hospital

Name of Rule	**Description of Rule**	**Number of flags**	**Positive predictive value, % (95%CI)**
Chest X-Ray			
Consolidation	Consolidation or opacity indicative of an infection	206	61 (54 – 68)
Pneumonia	Definite or possible pneumonia	44	89 (75 – 96)
Pleural Effusion	Report of definite or possible pleural effusion	108	81 (73 – 88)
Infection Syndromes			
Influenza			
Level 1	Influenza test order	200	100
Level 2	Pneumonia by x-ray	4	25 (0.6 – 80)
Level 3	↑/↓ WBC or bandemia	-	-
Level 4	Blood culture ordered	1	0 (0 – 98)
Level 5	Hospital admission	2	0 (0 – 84)
Pneumonia			
Level 1	Pneumonia by x-ray	209	51 (44 - 58)
Level 2	↑/↓ WBC or bandemia	49	43 (29 – 58)
Level 3	Blood culture ordered	8	62 (24 – 91)
Level 4	Hospital admission	12	75 (43 – 95)
Level 5	Critical Care admission	1	100
Infectious Diarrhea	Stool culture ordered	12	0 (0 – 26)
Infectious lymphadenitis	Microbiology test ordered for lymph node source	2	0 (0 – 84)
Nonrespiratory Viral test	Viral test from non-respiratory specimen	263	10 (7 – 14)
Sepsis			
Level 1	Critical care admission	132	100
Level 2	Blood culture ordered	10	100
Level 3	↑/↓ WBC or bandemia	6	66 (22 – 95)
Meningitis	Confirmed meningitis	14	7 (0.2 – 0.3)
Unexplained Death	Death within 24 hours of hospital admission	3	0 (0 – 0.7)

The PPV for identifying patients with pneumonia and increasing acuity of illness improved with the higher levels of rules (Table 3), though there were smaller number of patients that satisfied the criteria for higher-level rules. The actual numbers of patients satisfying criteria for and the PPV for groups of rules used to identify patients with confirmed sepsis, meningitis, infectious diarrhea and unexplained death was low in this study.

Discussion

A novel electronic medical record-based public health surveillance system was developed specifically for the 2002 Winter Olympic Games and used exclusively at the University of Utah School of Medicine. Along with medical informaticists and information technology teams, infection control unit personnel played a key part in the development and monitoring of the system. The data stream resulting from this system contributed to the public health surveillance of the region during the high alert period of the Olympics, which were conducted 4 months after the anthrax attacks of 2001. Apart from an increase in seasonal influenza activity, there were no events of significance noted during the surveillance period.

Several types of rules were developed for this system. Single data source rules were designed to identify occurrences of single important events (e.g., Test order for anthrax, test results for influenza). Other rules were focused on specific diagnoses such as pneumonia by chest x-ray. Groups of rules based on multiple data sources with patient level data were used as a proxy to identify infectious syndromes.

The goal of surveillance in public health is to identify unusual patterns of symptoms that could represent clusters of illness, with the hope of identifying these events of significance in a timely manner so as to allow an adequate public health response and management. With the advent of emerging infections and intentional release of agents of bioterrorism, many health care entities and public health departments have been involved in syndromic surveillance, in an attempt to identify illnesses at earlier stages of an outbreak. These have involved using chief complaint data from the emergency room, ICD-9 diagnoses, laboratory orders and other novel data sources (1, 2, 12-14). Though significant progress has been made in developing these surveillance systems, evaluations of functioning systems have shown deficiencies in their ability to detect unusual occurrences (15). A common limitation has been the lack of immediate access to detailed patient-level data. A different paradigm is to develop health care system-centric bio-surveillance systems with access to timely and detailed clinical data. Our system was designed to harness the power of the real-time electronic medical record and play a supportive role to local public health authorities in detecting disease clusters.

One distinct advantage of this system is the ready access to the detailed electronic medical record. Once an alert is generated by the system, instead of automatically transmitting that alert to the public health authorities, the infection control practitioner is able to access the system and perform a rapid, preliminary assessment to classify the alert as significant, potentially significant requiring more data or false. This locally performed step has the potential to decrease the number of false positive alerts that the public health authorities will have to investigate. On the other hand, this system could also serve a bi-directional purpose, in that it could respond to queries from local, state and federal public health authorities. Based on occurrences in other parts of the country or world, the system could be accessed with specific rules (either existing or new) to see if any specific infection or occurrence was noted at the individual hospital level (either retrospectively in a particular time frame or prospectively from time of query).

Several limitations were noted in our study. The system was functional at only one institution and was evaluated during a limited time frame during the 2002 Winter Olympics. It is important to note that to detect a regional increase in disease during the Olympics, local and state public health agencies were separately monitoring for unusual occurrences by electronic surveillance (11), manual review of emergency department logs and sentinel and individual provider reporting. The PPV associated with the rules used in this system was found to vary, with a high PPV noted for identification of pneumonia by natural language processing. Overall, there were too few events occurring for several infectious syndromes to be able to reliably calculate PPV. Though, as described here, the system uses a comprehensive electronic medical record and medical informatics support that may preclude widespread use, a basic surveillance system could be developed to run on existing admission-discharge-transfer (administrative) and laboratory data that are available in most health care systems.

With the threat of bioterrorism and emerging infectious diseases and the realization that exposed patients will be seen in outpatient clinics and hospitals under their purview, infection control practitioners have become cognizant of an added role in public health surveillance. This surveillance system provides the necessary tools to monitor local health care sites. Also, by selectively monitoring and automating the alerts to be sent by email, pager or cell phone, this system could be activated during times of high profile events and increased national threat level, when the potential for unusual occurrences may be considered high.

The successful, rapid development and deployment of this system was possible because of collaborations that exist between hospital infection units, information technology personnel, private resources and public health agencies in the Salt Lake City area. More studies are needed to further refine the rules and perform more complete evaluations of the system, possibly with a wider region-wide adoption of the system.

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CHAPTER 3

COMPUTER-BASED DETECTION OF CENTRAL NERVOUS SYSTEM SYNDROMES FOR PUBLIC HEALTH SURVEILLANCE

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Abstract

Background. Meningitis and encephalitis are infections of substantial public health interest. While computer-based surveillance methods (CBSM) have been used with success in the early detection of respiratory syndromes, there is little experience with their use in central nervous system (CNS) syndromes.

Methods. A clinical standard of cases of meningitis/encephalitis were established based on positive microbiological results of the CSF and review of the electronic medical record for patients seen in the emergency department (ED) of a large tertiary care hospital between January 1, 2002 and July 31, 2004. Computer rules were applied to the same ED data, to identify patients with possible diagnoses of meningitis/encephalitis. Five rules were compared, ranked on the timeliness of availability of data with respect to initial presentation: 1) "Reason for visit" to the ED with text indicative of neurological symptoms; 2) Laboratory orders for cerebrospinal fluid (CSF) testing in the ED; 3) Initial abnormal CSF results available within 24 hours of ED visit; 4) ED requests for head imaging on non-trauma and non-cancer patients and 5) ICD-9 coding of ED visits. Combinations of rules and time-stamps of availability of data were used to determine test characteristics as compared to the clinical standard. Completeness and timeliness of reporting of cases to the local health department was determined by comparison with health department data.

Results. A total of 53,015 patients accounted for 86,661 ED visits during the study period. The clinical standard identified 116 cases (0.13%) of meningitis and encephalitis. The computer rules 1 - 5 identified 3635, 871, 78, 2814, and 184 visits with possible CNS syndrome diagnoses respectively. The single most sensitive rule was laboratory orders (91%, ROC 0.95), followed by ICD coding (62%, ROC 0.8). The specificity of the five

rules ranged from 96 – 99.9%. A neurological "reason for visit" to the ED was a poor predictor. All rules demonstrated a high negative predictive value while ICD coding had the highest positive predictive value of 39%. Combining rules 2-5 into a single predictive model (any one rule present) had an area under the ROC curve of 0.98. Of 73 patients who had the potential of being reported to the local health department, 4 were found in the local health department database. The average time between laboratory test date and notification to the local health department was 2.5 days.

Conclusion. True CNS syndromes caused by infectious agents represent a small proportion of patients seen at the ED of a large tertiary hospital. "Reason for visit" chief complaint data were poor predictors. CSF laboratory testing, the second timeliest rule, had the highest sensitivity. Public health reporting is neither complete nor timely. A pilot public health surveillance system based on these rules has been developed that has the potential for improving detection and reporting of CNS syndrome.

Introduction

Meningitides and encephalitides are rare but important diseases of the central nervous system that often present as acute illnesses characterized by fever, headache, neck stiffness, seizures, altered sensorium and other neurological symptoms. These syndromes are caused by a variety of micro-organisms including bacteria, viruses and fungi. Emerging diseases such as West Nile Virus and NIH/CDC Category B pathogens such as Venezuelan, Eastern and Western Equine Encephalitis also present as CNS syndromes (1). While most CNS syndromes occur sporadically, the acute presentation, accompanying personal and public concern and potential for adverse outcomes including death make them high-profile occurrences. The mass media is usually the forum for learning about the college athlete who dies of meningococcal meningitis or widespread occurrence of West Nile Virus in an area. Apart from the morbidity and mortality caused by these diseases, there are certain cases that require prompt public health action. Close contacts of cases of meningococcal meningitis should receive prophylactic medications as soon as possible after the exposure to prevent disease. The detection of West Nile Virus has a broader implication for public awareness, education and vector control measures in conjunction with other public health agencies.

The diagnosis of CNS syndromes is often based on the history and clinical presentation. While some test results are returned in hours facilitating diagnosis of certain bacterial, viral and fungal diseases, most diagnoses are delayed and may take several days for confirmation. Despite modern methods of testing, nearly 60% of all cases of CNS syndromes remain undiagnosed with respect to an etiological agent (2, 3).

Several CNS syndromes such as meningococcal meningitis and West Nile Virus encephalitis are reportable diseases in many states including Utah. As the confirmation of the diagnosis may be delayed, the reporting of these syndromes from providers and laboratories to public health authorities is often delayed and incomplete, even in situations where the reporting is automated (4-6). There exists a need for the early detection of CNS syndromes and a mechanism for the prompt identification of reporting of cases that would represent an event of public health interest.

Computer-based surveillance systems have been extensively used in emergency departments, hospitals and public health departments for the prompt recognition of events of public health significance using syndromic surveillance (7). While respiratory syndromes have been extensively studied in this field, there is little data on the computer-based detection (CBM) of CNS syndromes (8-10). Simple computer-based rules that can monitor existing hospital information systems have the potential to be used for CNS surveillance. This study was undertaken to validate the early detection of CNS syndromes using computer-based methods and to determine the test characteristics of selected computer-based rules.

Setting

This study was carried out at the emergency department (ED) of University Health Care in Salt Lake City, Utah. This is a large tertiary care academic medical center ED that is staffed 24X7X365 by emergency medicine physicians, providers and nursing staff. The ED serves as a referral center for a large patient base from the local communities in the state of Utah and a surrounding four state region. The ED serves approximately 36,000 patients per year in urgent and emergent visits. Nearly all of the patients seen in the University Health Care ED are adults as there is a tertiary care children's hospital adjacent to University Health Care that manages pediatric patients. The ED has an integrated information system that consists of an electronic medical record, laboratory, radiology and pharmacy records. The data are stored in a central data repository and can be accessed and linked to other administrative databases such as the admit-transfer-discharge database.

Methods

This was a retrospective study that analyzed the electronic medical records of patients presenting to the University Health Care ED between January 1, 2002 and July 31, 2004.

A clinical case definition for CNS syndromes was developed and used to identify patients that had a confirmed CNS syndrome (Clinical Standard). The case definition was based partly on the Bacterial Meningitis Score (11, 12) and stated that a patient with a CNS syndrome was a patient who had an abnormal cerebro-spinal fluid (CSF) analysis of >5 white blood cells per high power field AND whose diagnosis of either meningitis or encephalitis was confirmed by review of the microbiological database for evidence of micro-organisms or other laboratory results such as PCR or serology. This was supplemented by manual review of electronic medical records for admission reports, progress notes, consult notes from infectious disease specialists and neurologists and discharge summaries. To avoid misclassification of cases and to estimate CNS cases among patients that did not have a CSF order of result, patients who did not have a CSF order and had a final ICD-9 diagnosis containing any of the Electronic Surveillance for the Early Notification of Community-based Epidemics (ESSENCE) neurological symptoms codes (acute delirium 293.0, confusional state 293.1, tension headache 307.81, alteration of awareness 780.02 & 780.09, convulsions other 780.39, headache 784.0 and aphasia 784.3) (13) were first extracted. Electronic medical records of a random sample of 100 of these patients were reviewed to determine their final diagnoses. The review for the determination of clinical standard cases was performed by AVG.

Five rules were developed for the computer-based detection of CNS syndromes; they were, in chronological order of availability as the patient is being evaluated in the ED: (1)

"Reason for visit" to the ED chief complaint with text indicative of neurological symptoms; (2) A laboratory order for CSF testing in the ED; (3) Orders for head imaging such as head CT or MRI that were not related to trauma or cancer patients, (4) Initial CSF results available within 24 hours of being registered in the ED and (5) ICD-9 coding of ED visits that were usually available with 2-14 days of the ED visit. The free text fields of chief complaint or reason for visit to the ED were manually mapped to neurological symptoms that corresponded to the ESSENCE neurological codes for symptoms (13). For example, "head pain" or "pain in the head" were mapped to headache; seizures or epilepsy were mapped to convulsions; altered consciousness or altered mental status or mental status changes or decreased level of consciousness were mapped to alteration of awareness. The ICD-9 coding rule was based on the codes used for meningitis and encephalitis by the ESSENCE project (13).

The test characteristics of the cases identified by the computer rules were determined by comparing them to the Clinical Standard cases using Stata 9.2 statistical software (College Station, Texas). Permutations and combinations of rules were examined. The receiver operating characteristic (ROC) curves were calculated for a binary test according to the method of Cantor and Kattan (14). Finally, the completeness and timeliness of public health reporting of confirmed cases of meningitis and encephalitis was determined by comparing the microbiologically confirmed cases that that had the potential to be reported to the local health department with records from the local health department.

The study was reviewed by the Institutional Review Board of the University of Utah.

Results

There were 53,015 unique patients seen in 86,661 visits to the ED during the study period. A detailed review of 563 patients with abnormal CSF results to determine cases of meningitis and encephalitis according to the Clinical Standard revealed a total of 116 cases (Table 4). These represent 0.2% of all patients seen and 0.13% of all visits. These included cases that were community-acquired, hospital-acquired and had risk factors such as recent neurosurgery or devices in situ. The review of 100 randomly selected visits among 3444 patients that had an ESSENCE neurological symptom ICD-9 code as the primary diagnosis and did not have a CSF order or result yielded no new cases of meningitis or encephalitis (97 cases were confirmed to not have these diagnoses and details of three visits could not be found after searching through two different electronic databases). Thus, the prevalence of CNS syndromes in this cohort was very low.

The most common diagnosis was aseptic meningitis with no microbiological cause found for the abnormal CSF (41, 35%). Bacterial causes included *Staphylococcal aureus* (10, 9%), *Streptococcus pneumoniae* (3, 3%), other Gram-positive and Gram-negative bacteria (31, 27%), Viral including herpes simplex, cytomegalovirus, enterovirus, Epstein-Barr virus, West Nile Virus and other arbovirus (24, 21%) and fungal including Cryptococcus and candida (5, 4%). Two cases were classified as encephalitis.

The first computer rule of neurological "reason for visit to the ED" identified 3635 (4.2%) visits with chief complaint free text fields that were indicative of a neurological symptom as defined by the ESSENCE code list. The other rules identified 871 (1%) patients by CSF orders, 78 (0.1%) by initial CSF results, 2814 (3.3%) by radiology orders, and 184 (0.2%) by final ICD-9 coding.

Table 4. Etiologic diagnoses of clinical standard cases of meningitis and encephalitis

Final Diagnosis	**Number (%) Total = 116**	**Potential for reporting to public health**
Aseptic Meningitis	41 (35)	No
Bacterial		
Staphylococcus aureus	10 (9)	Yes
Streptococcus pneumoniae	3 (3)	Yes
Coagulase negative staphylococcus	9 (8)	Yes
Propionibacterium acne	7 (6)	Yes
Other bacteria	15 (13)	
Viral		
Herpes simplex virus	9 (8)	Yes
Cytomegalovirus	6 (5)	Yes
Enterovirus	5 (4)	Yes
Epstein-Barr Virus	2 (2)	Yes
West Nile Virus	1 (1)	Yes
Other Arbovirus	1 (1)	Yes
Fungal		
Cryptococcus neoformans	2 (2)	Yes
Candida albicans	1 (1)	Yes
Aspergillus species	1 (1)	Yes
Yeast, not candida	1 (1)	Yes
Encephalitis	2 (2)	No

When compared to the Clinical Standard, the rules showed a range of test characteristics (Table 5 and Figure 3). The chief complaint text field was a very poor predictor of meningitis or encephalitis with a sensitivity of 12% and a positive predictive value of 0.4. The single most sensitive rule was laboratory orders (72%, ROC 0.95), followed by ICD coding (62%, ROC 0.8). The specificity of the five rules ranged from 96 – 99.9%. All rules demonstrated a high negative predictive value while ICD coding had the highest positive predictive value of 39%. All permutations and combinations of rules 2-5 were examined. Combining the CSF lab order rule as an "or" rule with either CSF result, radiology orders or ICD-9 coding improved the sensitivity to 100% with only one concomitant improvement in positive predictive value. Combining the CSF orders as an "and" rule with the others improved the PPV with loss of sensitivity. Combining the rules into a single predictive model (any one rule 2-5 present) had an area under the ROC curve of 0.98.

Time stamps of when CSF tests and radiology imaging studies were ordered in relation to the ED log-in time were partially beneficial for improving test characteristics (Table 6). CSF lab orders at within 2 hours of being logged in to the ED as a patient had the highest sensitivity when compared to a clinical standard, though the PPV was very low and the area under the ROC curve was not significant. From 4-24 hours, the sensitivity dropped significantly and then recovered to 71% at 24 hours. Radiology orders at all times in the first 24 hours performed poorly in terms of sensitivity (1-31%) and PPV (1).

ICD-9 codes referring to specific causes of meningitis and those that pertained to neurological symptoms were in general poor predictors. ICD-9 codes that collectively

Table 5. Test characteristics of computer rules

Rule	Flags (%) N=86,661	Sens	Spec	PPV	NPV	ROC
Neurological "Reason for visit to the ED" – Chief Complaint	3635(4.2)	12	95.8	0.4	99.9	0.54
R1 Diagnosis by lab order	871 (1)	90.5	99.1	12.1	100	0.95
R2 Diagnosis by lab result	78 (0.1)	19	99.9	28.2	99.9	0.6
R3 Diagnosis by radiology	2814 (3.25)	42	96.8	1.74	99.9	0.7
R4 Diagnosis by ICD-9 Coding in the ED	184 (0.2)	62	99.9	39	99.9	0.8
Any rule (R1 or R2 or R3 or R4)	2991 (3.5)	100	96.7	4	100	0.983
All rules (R1 and R2 and R3 and R4)	11 (0.01)	9.5	100	100	99.9	0.55
R1 or R2	172 (0.2)	100	99.9	67.4	100	1
R1 or R3	2881 (3.3)	100	96.8	4	100	0.984
R1 or R4	228 (0.3)	100	99.9	51	100	0.999
R2 and R4	34 (0.04)	16	100	53	99.9	0.6

Sens = sensitivity
Spec = specificity
PPV = positive predictive value
NPV = negative predictive value
ROC = receiver operating characteristic - area under the curve

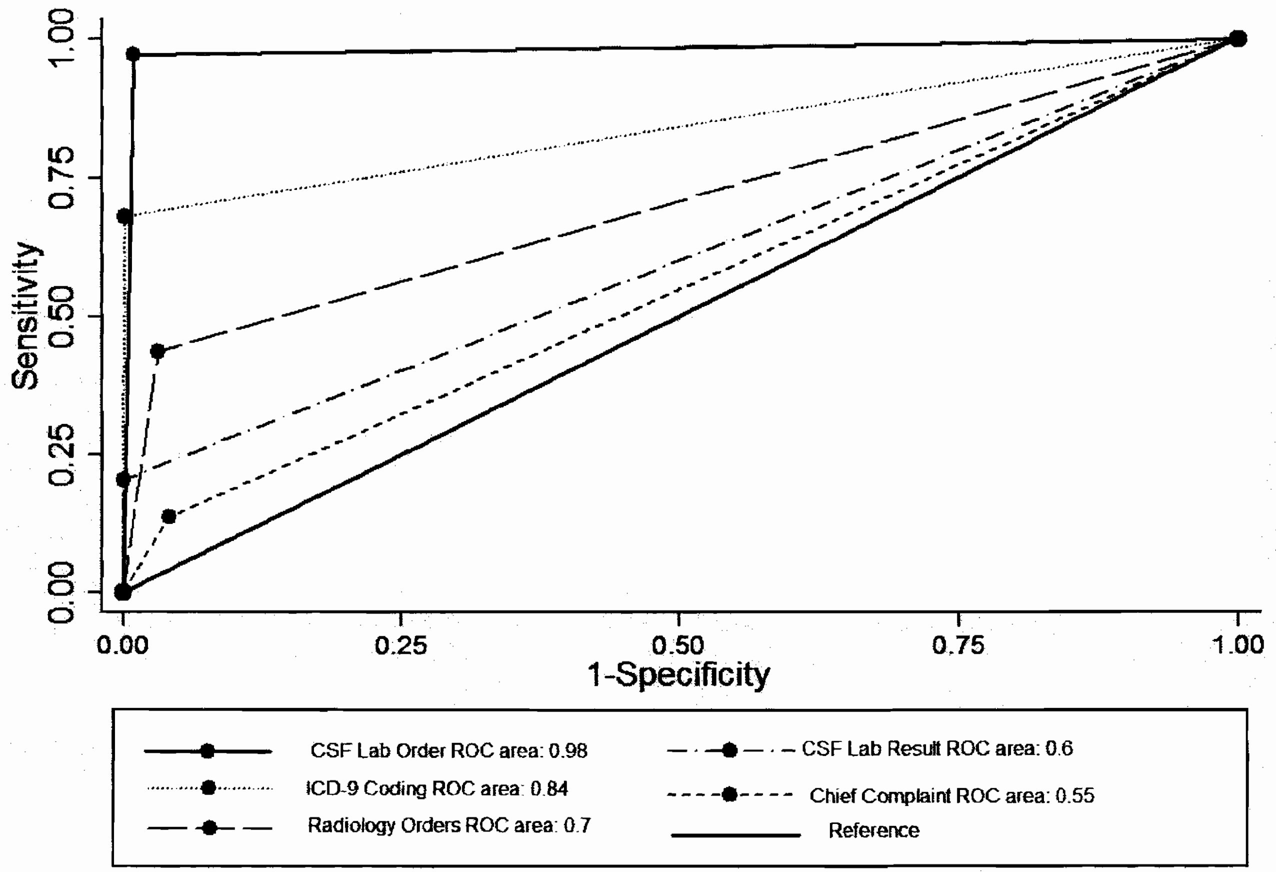

Figure 3. Receiver Operating Characteristics of computer rules

Table 6. Test characteristics of computer rules based on availability of data and specific ICD-9 coding

Rule	Flags (%) N=86,661	Sens	Spec	PPV	NPV	ROC
Lab order at 2 hours	93 (0.1)	91	99	12	100	0.5
Lab order at 4 hours	278 (0.3)	25	99.7	10	99.9	0.6
Lab order at 6 hours	411 (0.5)	46	99.6	13	99.9	0.7
Lab order at 12 hours	519 (0.6)	57	99.5	13	99.9	0.8
Lab order at 18 hours	562(0.7)	66	99.4	14	100	0.8
Lab order at 24 hours	597 (0.7)	71	99.4	14	100	0.85
Radiology order at 0 hours	82 (0.1)	1	99.9	1	99.9	0.5
Radiology orders at 1 hour	600 (0.7)	5	99.3	1	99.9	0.5
Radiology orders at 2 hours	1222 (1.4)	12	98.6	1	99.9	0.5
Radiology orders at 4 hours	1970 (2.3)	21	98	1	99.9	0.6
Radiology orders at 6 hours	2215 (2.6)	22	97.5	1	99.9	0.6
Radiology orders at 12 hours	2423 (2.8)	28	97.2	1	99.9	0.6
Radiology orders at 24 hours	2604 (3)	31	97	1	99.9	0.6

Sens = sensitivity
Spec = specificity
PPV = positive predictive value
NPV = negative predictive value
ROC = receiver operating characteristic - area under the curve

referred to bacterial meningitis (from the ESSENCE listing, Table 4) had a sensitivity of 25%, a specificity of 100% and a PPV of 58. Those that referred to viral causes had a sensitivity of 26% and a PPV of 41. Though the numbers were small for herpes virus related ICD-9 codes (7), the PPV was 86. ICD-9 codes for ESSENCE neurological symptoms (either as primary code or in any sequence) were also poor predictors. *The public health reporting of CNS syndrome cases was not complete, though the limited reporting was timely to the local health department.* Although all 116 clinical standard cases are reportable to public health agencies, in reality, the 73 that had a positive microbiological result are the cases that would have come to the attention of hospital epidemiology unit and had the potential to be reported to the local health department (Salt Lake Valley Health Department). Of these, only four cases (3%) of meningitis (one each of enterovirus, Cryptococcus, *Staphylococcus aureus* and *Streptococcus pneumoniae*) were in the local health department database as being reported from our institution. The average reporting time was 2.5 days (range 0-7 days) from date of laboratory test and this is consistent with the reporting requirement of reporting these types of meningitis within 3 working days after identification. Interestingly, there were three cases of meningitis due to coccidioidomycoses in the local health department database attributed to our institution that were not in our database. A review of the state department of health (Utah Department of Health) revealed the same 4 cases and in addition, one case of West Nile Virus neuro-invasive disease. The average time of receipt of notification at the state health department was 8 days (range 4-14 days). From the available data available, it is not clear whether the report originated from our hospital or the clinical laboratory that performed the test. Thus, the public health reporting of meningitis and encephalitis cases to the local health department is not complete.

Conclusions

This study demonstrates that computer rules based on simple criteria that can be deployed to run on existing clinical information systems have the potential to detect CNS syndromes such as meningitis and encephalitis. While the sensitivity varied among the rules, the important result may be the extremely high negative predictive value of the rules. Though the exact rules were different and our patient population was predominantly adult, this is consistent with the clinical prediction rules for identifying children at very low risk of bacterial meningitis using the Bacterial Meningitis Score (11). These rules move the detection of CNS syndromes beyond the focus of chief complaint "reason for visit to the ED."

Combinations of rules have improved test characteristics and in reality, this may be practical approach to take in performing electronic surveillance for patients that could represent CNS syndromes.

Overall, true CNS syndromes caused by infectious agents represents a very small portion of patients seen at a large tertiary hospital. In this situation, the identification and timely notification of these patients to hospital epidemiology and subsequently to public health may be delayed. In one study, the median time for reporting cases of bacterial meningitis to national public health using the National Electronic Telecommunications System for Surveillance was 20 days (4) and later shown to be 12 days using the National Notifiable Diseases Surveillance System (6). It is likely that this time frame is shorter for reporting to local public health but not early enough to initiate appropriate interventions if they are needed. A personal communication from the Salt Lake Valley Health Department indicates that it takes 3 days for a report of meningococcal meningitis to reach the local health department via the usual channels of notifiable disease reporting.

At the present time, our institution does not actively solicit CNS cases and the infection control practitioners rely on microbiological result notification or medical providers to be alerted to a case of community- or hospital-acquired meningitis. In this situation, the development of an automated surveillance system may be of benefit to alert the hospital infection control personnel to all possible CNS cases. These can then be communicated to the local health department in a complete and timely manner. Based on the organism and circumstance, the public health agencies can then initiate an investigation on nearly all the potential cases and intervene as necessary. The local health departments are interested in community-acquired cases of bacterial or viral meningitis as well as clusters of CNS infection associated with surgeries or devices.

Early detection of CNS syndromes has potential benefits. Any lead time in the diagnosis of a case of meningococcal meningitis would decrease the contact tracing involved and limit the number of individuals that need to be given prophylaxis or vaccinations. In the case of an emerging disease such as West Nile Virus, the early diagnosis of human cases combined with mosquito and sentinel chicken monitoring programs could lead to targeted public education campaigns. A similar situation arises with clusters of meningitis associated with neurosurgical procedures or the presence of devices such as shunts. The early detection of a cluster of CNS syndrome patients with no specific etiologic diagnosis could lead to a prompt recognition of a new emerging disease or a category B agent.

There are several limitations to this study. The clinical standard was determined by reviewing a targeted subset of electronic records as the cohort was large (86,661 visits). Given the low prevalence of meningitis and encephalitis in our cohort and those reported elsewhere, it is likely that we did not miss many cases. It is noted that there is an overlap between how the clinical standard cases were identified and the computer rules of CSF lab order. The CSF test is a key component of the diagnosis of CNS syndromes and thus is used in both instances.

Future Directions

A hospital-based surveillance system utilizing existing electronic data in the emergency department and data warehouse has been developed in a prior study (15) and has now been validated for use in the detection of meningitis and encephalitis. Further validation of the rules and characterization of false positive and false negatives is currently under way along with plans to expand the system to provide near real-time alerts to hospital epidemiology. A mechanism to allow limited access of the surveillance system to local public health officials is also being considered as that would likely decrease the time to data acquisition and initiation of an investigation.

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CHAPTER 4

SIGNIFICANCE

The current state of public health surveillance is such that government and private entities have developed and implemented different surveillance systems for the early detection of outbreaks of diseases, both naturally occurring and intentional release. Apart from these, federal agencies such as the CDC and the Department of Defense have extensive networks of surveillance systems that are monitoring the nation's health. Historically, surveillance systems have focused on "syndromic surveillance" and have used chief complaint data for making inferences regarding outbreaks of disease.

The work presented in this master's thesis addresses important informatics and public health questions. The identification and extraction of pertinent clinical data are basic biomedical informatics questions. Presentation and analyses of these data in such a way that they are usable for surveillance are also fundamentally informatics challenges. On the other hand, the issues pertaining to the surveillance of diseases of clinical and public health interest fall in the realm of public health. This project combines both these fields in the form of *public health informatics*.

This thesis work represents a significant step in moving public health surveillance beyond the chief complaint alone. The first paper describes the work performed during the 2002 Winter Olympics wherein a hospital electronic medical record-based surveillance system was developed and deployed to monitor for disease outbreaks. The rules were developed to perform surveillance for a broad category of diseases, including central nervous system syndromes (CNS) such as meningitis and encephalitis.

The second paper describes a continuation of this electronic data surveillance wherein specific rules were developed to detect cases of meningitis and encephalitis. The rules were validated against a clinical standard of cases and shown to have utility for the detection of these cases. While single rules were of benefit, combinations of rules may have a practical application in the surveillance for CNS syndromes.

The second paper has also examined the challenging task of public health reporting of CNS cases from health care institutions to health departments. The State of Utah statute for the reporting of CNS cases in Utah calls for the reporting of ALL infections of the cerebrospinal fluid, whether community- or hospital-acquired. In a practical sense, our institution currently reports only those that are considered community-acquired. Though the prevalence of CNS infections is low, it is resource intensive to perform active surveillance for these infections in the absence of an electronic method of identification. The simplest method is the electronic notification of a positive microbiological result from the usually sterile cerebro-spinal fluid (CSF). This currently occurs at our institution and results in notification of confirmed cases of meningitis. As shown by this thesis research, the reporting is reasonably timely to the local health department, however it is incomplete. This is an area of improvement that would need to be addressed in future work as improving timeliness of reporting of notifiable diseases would be of benefit to the public.

Lessons learned

The first lesson learnt during the course of this thesis project is that inter- and multidisciplinary collaboration is of primary importance in developing surveillance systems. While the authorship has considerable experience in biomedical informatics and public health informatics in particular, the project has drawn on expertise in the fields of information technology, clinical emergency medicine, infection control and statistics. Finally, an active collaboration with public health personnel in both local and state health departments was key in first inspiring and then shaping the project.

The second lesson is that surveillance systems in general are easy to develop. The challenge lies in validating them, successful deploying them and then proving their utility for detecting the appropriate signal. This project has successfully developed hospital-based surveillance system using electronic data that currently exists at our institution. Validation has been completed for an important category of disease, namely neurological syndromes such as meningitis and encephalitis. We are also confident that the appropriate signal can be detected. Further work is required to deploy this system on a scale that is practical for the institution and portability to other health care systems.

Future Work

The fundamental mistake that can be made while working on a project is to declare it completed and set it on the shelf to gather dust. In an attempt to prevent this surveillance project from decaying, the primary author with the rest of the authorship has initiated an active collaboration with colleagues at the local Salt Lake Valley Health Department and the state Utah Department of Health. All parties concerned are interested in further exploring this surveillance system for CNS infections and deploying the system on a scale that is both practical and useful.

One of the first future projects will be to provide outputs from the surveillance system to the infection control practitioners in our own institution. This should facilitate the identification of CNS cases at our facility and automate their reporting to public health. The intent here is to improve reporting in terms of ease of use, completeness and timeliness.

The second level of sophistication is to allow our colleagues from the local health department to access a limited version of the surveillance system. This will provide them with a snapshot of what is occurring at our institution along with an option for them to "pull" their own reporting data, rather than wait for us to "push" the data to them. With appropriate safeguards in place to protect the confidentiality of patients, this level of access should be achievable as this is consistent with the public health mission of the hospital. This may improve the timeliness of reporting of notifiable diseases to public health agencies.

Another future project is to further validate the surveillance system and examine in detail the false positives and false negatives as compared to the clinical standard. This exercise will likely yield insights into the rules themselves and inform our refinement of the rules in the future.